Pergamon

Marine Pollution Bulletin Vol. 38, No. 12, pp. 1134–1140, 1999

Printed in Great Britain
0025-326X/99 $ - see front matter

PII: S0025-326X(99)00143-5

Beach Litter Sampling Strategies: is there a 'Best' Method?

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Ten methods for sampling beach litter were tested on 16 beaches located around the Firth of Forth, Scotland in order to ascertain the effectiveness of the various methods. Both fresh and/or accumulated litter were sampled. Some methods were more effective for recording gross amounts of litter. Maximum litter counts could be obtained by surveying the top boundary of the beach (e.g. vegetation line, retaining wall, rocks). Lowest amounts were obtained by surveying one five metre wide belt transect from the vegetation line to the shore. Some bias towards highlighting particular litter types was shown by specific methods. It was concluded that there were advantages and disadvantages for each method and that the aims of the study would in the end determine the method. © 1999 Elsevier Science Ltd. All rights reserved.

Keywords: marine debris; beach litter; sampling methods; principal component analysis.

Introduction

There are numerous methods used to sample beach litter and debris. It usually depends upon the type of litter being sampled, e.g. fresh tidal or accumulated litter. Often a method is based on one chosen from the literature (Evans *et al.*, 1995; Golik and Gertner, 1992; Khordagui and Abu-Hilal, 1994; Nash, 1992; Frost and Cullen, 1997; Uneputty and Evans, 1997). In other cases researchers repeat a method they have used in a previous study (Merrell, 1984; Dixon and Dixon, 1983; Dixon, 1995; Willoughby *et al.*, 1997). In comparative studies the methodology of the earlier work is repeated (Velander and Mocogni, 1998). However, since the data are collected in widely different ways, comparing studies can be very difficult and standardization of results is impossible. The question is raised – is there a 'best' method for assessing beach litter and debris, or is method irrelevant assuming the guidelines of the study are clearly explained? In this study beaches were sampled using ten variations of the methods listed below in an attempt to assess how the results varied depending on method. Clearly since some methods sample strand lines where there is an accumulation of litter and some sample transects which include large bare areas, there will be some differences. Similarly, methods that survey one small area of a beach, e.g. 10–15 m strip from vegetation to shoreline, can bias results on certain types of beaches, particularly on beaches where litter tends to accumulate in one specific area (Velander and Mocogni, 1998). However, this study attempted to quantify these differences. Hence, the aims of this study were to ascertain:

- whether or not the various methods produced significantly different results;
- whether or not some methods are biased towards sampling for specific types of litter;
- which method might be most effective.

Materials and Methods

Sixteen beaches were selected based on previous surveys that were carried out on the Firth of Forth (see Fig. 1). They included a mixture of sand/shell and sand/pebble beaches. Rocky areas were not surveyed. Each beach was visited on one occasion and all sampling was carried out at low tide between September 1996 and June 1998.

All litter was identified and recorded to either a specific item type or if this was not possible, the component material.

Ten methods were tested (see Table 1 and Fig. 2).

(1) 5 *wet strand lines*: A surveyor walked along 5 of the main strand lines (debris left in lines as tide recedes) from the most recent tide. The vegetation line was not included. The distance between strand lines varied depending on the high tide mark and the shape of the beach. Delineating the low tide line can be a problem, particularly on beaches in large shallow estuaries. For standardization, the low tide mark was defined as the point where the sand was permanently wet or where mudflats/sinking sands began. Litter was recorded over a 1 m wide strip.

(2) 5 *wet strand lines plus vegetation or top boundary line* (*referred to as vegetation line for the remainder of the paper*): as above, a surveyor sampled the five main strand lines along with the vegetation line, which tends

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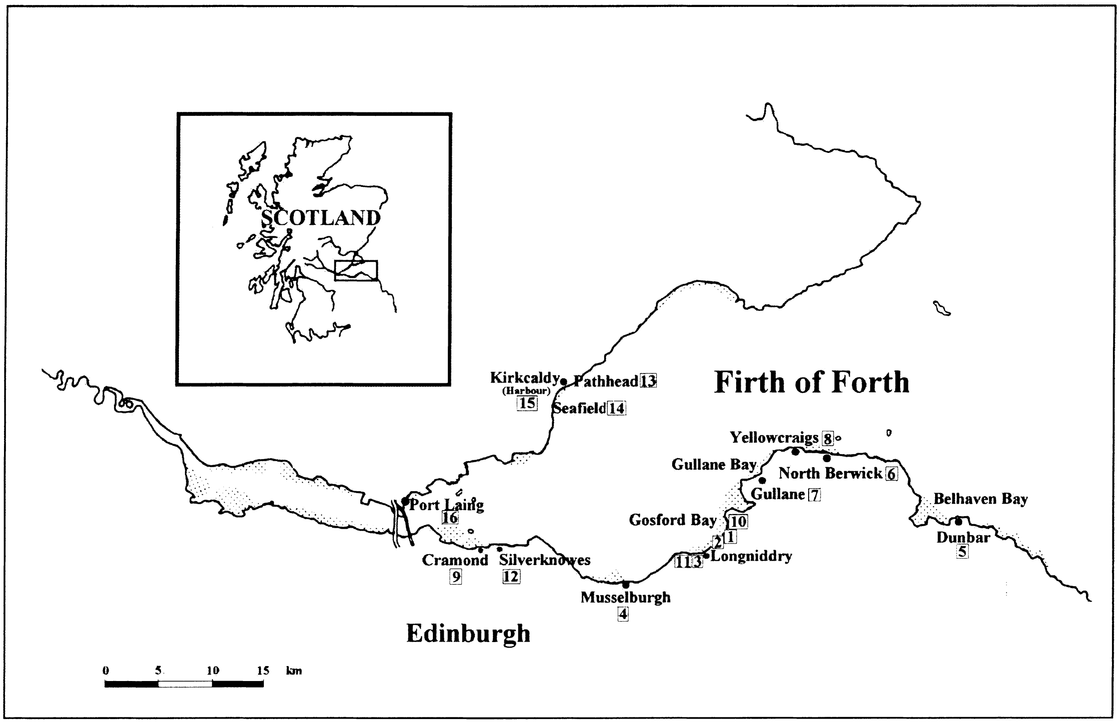

Fig. 1 Location of Sampling Sites on the Firth of Forth, Scotland.

to trap and hold more litter from past tides, winds, etc. Litter was recorded over a 1 m strip.

(3) *Top, bottom and vegetation lines*: as above, but only along the top (strand line 5, wet), bottom (strand line 1, wet) and vegetation line (dry). Litter was recorded over a 1 m strip.

(4) 5 m *wide belt transect*: three 5 m wide transects were marked out from the vegetation line to the water's edge or bottom strand line. All the litter within this area was counted. The sampling points were evenly spaced along the 100 m stretch. This transect included both wet and dry areas.

(5) 1 m *wide belt transect*: ten 1 m wide transects carried out at 10 m intervals from the vegetation to bottom strand line. This transect included both wet and dry areas.

(6) *Random*: the whole survey area was sampled in 2×2 m quadrats using a random number table to select sampling points.

(7) *Top alone* (strand line 5, wet). Litter was recorded over a 1 m strip.

(8) *Vegetation line alone* (dry). Litter was recorded over a 1 m strip.

(9) *Middle* 5 m *belt transect* (47.5–52.5 m, wet and dry).

(10) *Middle* 1 m *belt transect* (49.5–50.5 m, wet and dry).

TABLE 1

Summary of the ten sampling methods.

Method	Description	Composition of area surveyed	Fresh or accumulated litter	Area covered
1	Strand lines 1–5	Strand line transects (2,3,4 usually have minimal litter)	Fresh	500 m^2
2	Strand lines 1–5 plus vegetation	Strand line transects	Both	600 m^2
3	Strand lines 1 + 5+ vegetation	Strand line transects	Both	300 m^2
4	3 5 m: vegetation line to shoreline	Strand lines along with bare ground between	Both	$\bar{x} = 504$ m^2 (325 m^2–1245 m^2)
5	10 1 m: vegetation line to shoreline	Strand lines along with bare ground between	Both	$\bar{x} = 342$ m^2 (213 m^2 – 830 m^2)
6	2 m×2 m random	Everywhere	Both	80 m^2
7	Strand line 5 alone	Strand line	Fresh	100 m^2
8	Vegetation line only	1 m wide strip	Accumulated	100 m^2
9	5 m: vegetation line to shoreline	Strand lines along with bare ground between	Both	$\bar{x} = 173$ m^2 (107 m^2 – 415 m^2)
10	1 m: vegetation line to shoreline	Strand lines along with bare ground between	Both	$\bar{x} = 35$ m^2 (21 m^2–83 m^2)

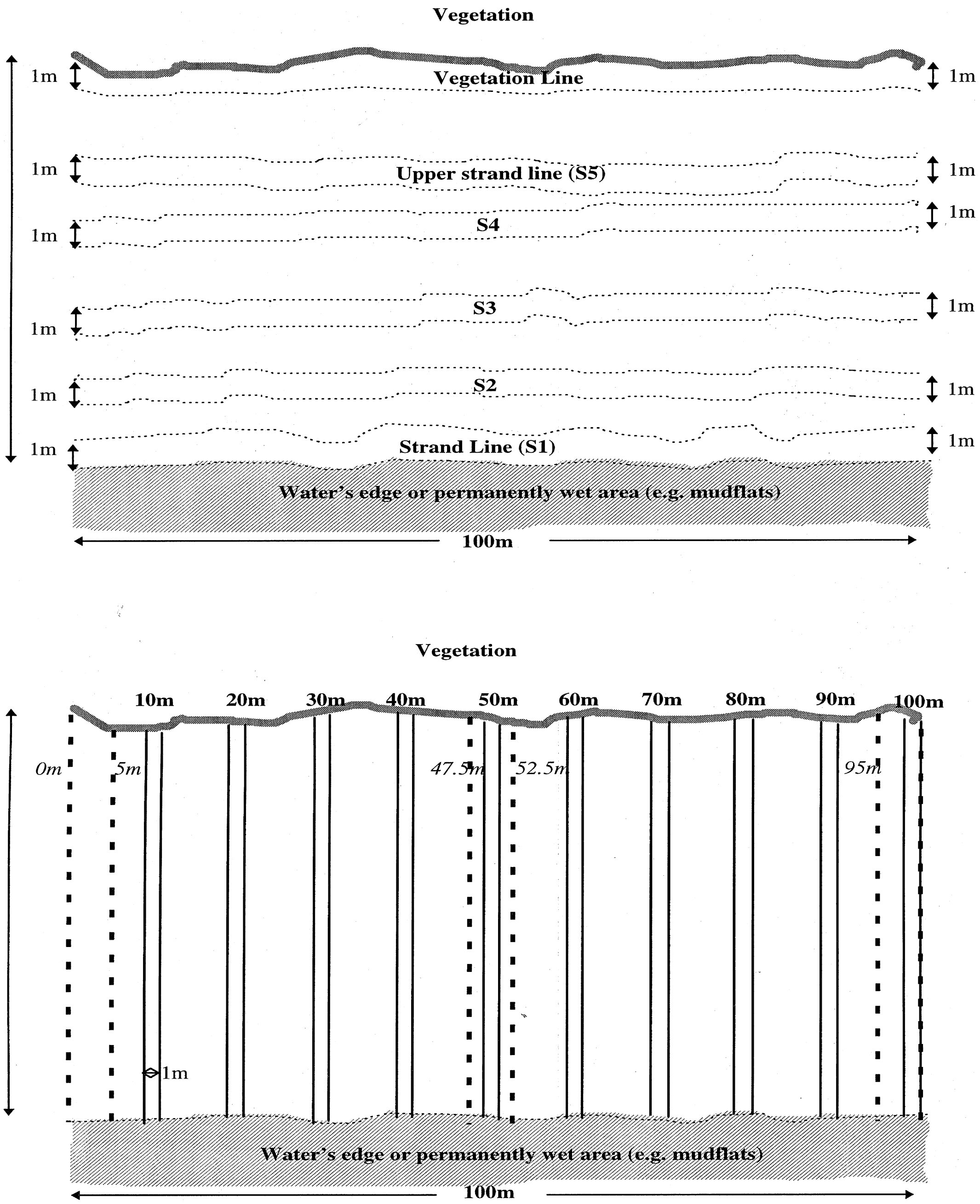

Fig. 2 Survey design for the ten methods.

Sampling procedure

A 100 m length of beach was measured and marked at 10 m intervals at the vegetation line and water or permanently wet mud/sand line. The location of the 100 m stretch was chosen at random. Pegs were also placed at 5, 47.5, 52.5 and 95 m (see Fig. 2) to enable three 5 m transects to be carried out at evenly spaced intervals along the 100 m. The distance from lowest strand line to vegetation line was measured at each peg and recorded for use when assessing the area covered by each method.

Only visible litter was counted. Litter was not collected or weighed. If large amounts of algae were present, it was not disturbed or searched for items entangled or hidden beneath.

Results

Table 2 summarizes the results of the surveys carried out on all 16 beaches using the 10 methods. In order to make a sensible comparison between methods, the data were expressed as the number of items of litter/m^2 as well as gross totals.

Does the amount of litter recorded vary with each method?

When an analysis of variance was carried out, it was noted that the amount of variability in the data increased as the mean increased. Fig. 3 shows boxplots of the amount of litter recorded for each method (the lines in the boxes represent the median values). The boxplots

TABLE 2

Gross and per m^2 totals for all surveys carried out using the 10 methods on the 16 beaches.

Method	1		2		3		4		5		6		7		8		9		10	
Site	Gross	/m^2	Gross	/m^2	Gross	/m^2	Gross	/m^2	Gross	/m^2	Gross	/m^2	Gross	/m^2	Gross	/m^2	Gross	/m^2	Gross	/m^2
1	96	0.19	166	0.28	142	0.47	134	0.30	125	0.42	32	0.40	33	0.33	70	0.70	18	0.12	10	0.33
2	46	0.09	119	0.20	81	0.27	32	0.09	42	0.13	14	0.18	6	0.06	73	0.73	6	0.04	2	0.06
3	52	0.10	93	0.16	63	0.21	47	0.13	51	0.20	25	0.31	18	0.18	41	0.41	13	0.10	4	0.16
4	56	0.11	86	0.14	65	0.22	26	0.06	56	0.21	6	0.08	29	0.29	30	0.30	10	0.07	3	0.11
5	47	0.09	62	0.10	31	0.10	21	0.04	27	0.08	9	0.11	2	0.02	15	0.15	3	0.02	3	0.09
6	76	0.15	257	0.43	216	0.72	68	0.12	85	0.23	22	0.28	27	0.27	181	1.81	23	0.12	12	0.32
7	5	0.01	13	0.02	12	0.04	16	0.03	22	0.07	6	0.08	4	0.04	8	0.08	4	0.02	5	0.15
8	135	0.27	237	0.40	151	0.50	133	0.18	118	0.24	50	0.63	44	0.44	102	1.02	33	0.13	9	0.18
9	295	0.59	418	0.70	336	1.12	115	0.27	243	0.83	77	0.96	185	1.85	123	1.23	37	0.25	7	0.24
10	243	0.49	862	1.44	793	2.64	611	1.88	562	2.63	206	2.58	153	1.53	619	6.19	189	1.77	50	2.34
11	433	0.87	500	0.83	219	0.73	201	0.46	217	0.73	106	1.33	102	1.02	67	0.67	69	0.47	12	0.41
12	76	0.15	252	0.42	216	0.72	66	0.19	139	0.64	41	0.51	32	0.32	176	1.76	15	0.12	19	0.76
13	30	0.06	119	0.20	104	0.35	63	0.12	51	0.14	25	0.31	15	0.15	89	0.89	29	0.16	4	0.11
14	137	0.27	548	0.91	458	1.53	132	0.27	178	0.54	35	0.44	21	0.21	411	4.11	34	0.21	17	0.52
15	58	0.12	200	0.33	168	0.56	48	0.13	40	0.16	7	0.09	25	0.25	142	1.42	21	0.16	6	0.24
16	129	0.26	387	0.65	348	1.16	142	0.11	118	0.14	22	0.28	89	0.89	258	2.58	80	0.19	11	0.13

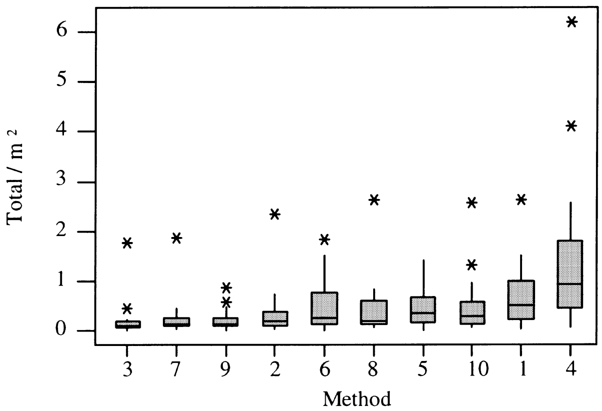

Fig. 3 Boxplots of the ten methods.

clearly show the skewed nature of the data, hence the data were transformed using natural logarithms. Once this was carried out the residuals from a two way analysis of variance were approximately normally distributed with a constant variance. The results showed that both the method ($p < 0.001$) and the site ($p < 0.001$) had a highly significant effect on the amount of litter recorded.

A Tukey's paired comparison procedure (Hogg, 1992) was carried out to clarify the results of the analysis of variance in order to ascertain which particular methods gave significantly different results (Table 3). At the 5% level of significance there were Honestly Significant Differences (HSD) between method 8 (vegetation alone) and all other methods in the total amount of litter. The other nine methods produced differing amounts of litter, but there was no clear relationship between amount of litter and general survey method. There was a tendency for those methods that included the total length of the vegetation line to have a higher mean, e.g. methods 2 (strand line 1–5 + vegetation) and 3 (strand lines 1 + 5 + vegetation). Method 6 (random) also produced a higher mean. The methods were ranked according to their order in the Tukey Comparison, these rankings are given in Table 3. The Tukey's paired comparison was not carried out for the 16 beaches, as it was clearly obvious from litter totals that the beaches were very different.

TABLE 3

Tukey's paired comparison of 'fitted' means per m^2 from the analysis of variance.

Method	Rank	N	Subset				
			1	2	3	4	5
9	1	16	0.1289				
4	2	16	0.1571	0.1571			
1	3	16	0.1578	0.1578			
10	4	16		0.2341	0.2341		
7	5	16		0.2662	0.2662		
5	6	16			0.2756	0.2756	
2	7	16			0.3073	0.3073	
6	8	16			0.3220	0.3220	
3	9	16				0.4642	
8	10	16					0.8943

Do some methods show a bias towards recording specific type of litter?

The second aim was to consider whether the different methods show bias towards different types of litter, e.g. are glass fragments more commonly found in transects which cover a higher proportion of bare ground, where it might be more obvious. Since so many types of items were recorded it was necessary to simplify the data into five categories which represented their component material, source or function. Plastics, glass, sewage-related debris, confectionery and containers were considered to be of the most interest either because of their relevance to health and safety or as indicators of beach pollution. Any items not fitting into these categories were classified as 'other'.

The relative quantity of each category of litter recorded for each method was analysed using Principal Component Analysis (see Fig. 4, Table 4). The coefficients in principal component one are all negative and of similar magnitude, except for glass. A high negative score on the first principal component represents methods that record high amounts of litter in general, but show no bias towards particular categories. In Fig. 4, this is represented by most of the data points occurring within the main cluster, but with some points appearing to the left of the cluster representing those method/site combinations that produced a high mean litter count. Method 8 (vegetation only) and to some extent method 3 (1 + 5 + vegetation) are shown to be different from the other methods. The Eigen analysis of the correlation matrix attributes 67% or the variability within the data set to the first principle component.

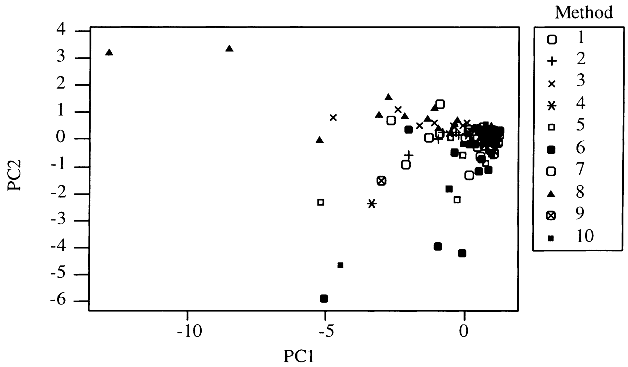

Fig. 4 Plot scores on the first and second principal components by method.

TABLE 4

Coefficients for the first two principle components.

Variable	PC1	PC2
Drinks containers and confectionery	−0.454	0.414
Glass fragments	−0.184	−0.900
Sewage-related debris	−0.485	−0.125
Plastics	−0.505	0.057
Other	−0.519	0.019

The second principal component separates observations which have either high quantities of drinks containers and confectionery wrappers or glass fragments. The observations with high quantities of drinks containers and confectionery had high positive scores on this component and those with a high quantity of glass fragments had high negative scores. In Fig. 4, method 8 (vegetation only) and method 3 (1 + 5 + vegetation) appear to be recording higher proportions of drinks containers and confectionery items, while method 6 (random) is picking up a higher proportion of glass fragments. Large quantities of specific litter types accounted for 21% of the variability in the data as shown by the Eigen analysis, thereby attributing 88% of variability within the data to these two components.

Are some methods more effective than others?

Finally, was there a difference between methods, are some methods more effective than others? When looking at the results, certain methods showed a higher per m^2 figure for litter than others. The two highest were method 8 (vegetation only) and method 3 (1 + 5 + vegetation).

Discussion

The methods chosen for surveying litter, clearly depend on the objectives of the study, e.g. whether assessing fresh tidal, accumulated litter or both. This was accounted for in this study by ensuring the methods recorded a variety of information about litter distribution on each beach. Some methods sampled only the tidal or fresh litter areas. Others sampled the accumulated litter only (e.g. above the normal top strand line, these areas would include storm dispersed litter along with that distributed by wind), while still others sampled both. Similarly if the presence of a specific type of item is the aim of the study (e.g. containers, glass), some methods are better than others.

It can be seen from the rankings in Table 3 that method 8 (vegetation only) gave the highest amount of litter. Similarly methods that surveyed the total vegetation line (e.g. methods 2 and 3) were also highly ranked. This is as expected, since litter tends to accumulate both along the vegetation line and along the top wet strand line. Not surprisingly any methods that included the areas between the strand lines, tended to have lower amounts of litter recorded, in particular method 9 (one 5 m vegetation to shoreline belt transect), although method 1 which included 5 strand line transects on the wet sand area also gave lower mean figures. The lower wet strand lines usually have only small amounts of litter, thereby when a per m^2 average includes these areas, a lower figure results. Unfortunately for the study, but fortunately for the Forth, none of the beaches could be considered as really dirty since the maximum amount of litter per m^2 was only 6.2 pieces/m^2 (range from 0.01 to 6.2) compared with 21.5 pieces/m^2 found by

Uneputty and Evans (1997) in Indonesia. It may well be that with higher amounts of litter, the methods would be more discriminatory. Regardless, the overall conclusion is that the different methods did produce significantly different results and care must be taken when selecting a method to ensure the one chosen is appropriate to the task.

Secondly, the possible bias towards any methods consistently showing a higher amount of any specific type of litter was considered. Method 6 (random) showed a higher number of glass fragments, while method 8 (vegetation only) had more containers. This is not surprising since the random method frequently fell on bare areas which had only glass. By comparison the other methods which included the bare areas between strand lines, recorded other types of litter present on the strand lines to offset the large amounts of glass. Similarly containers are very light and often catch in the vegetation line when they are being blown about the beach. Hence, if a beach is being surveyed for a specific reason, e.g. to record the number of aluminium drinks cans in order to estimate the use of the beach by tourists, a method which highlights these items would be most appropriate.

When considering the effectiveness of each method, several factors must be considered. Firstly the parameters must be defined. Does effective mean giving a high, medium or low figure for the amount of litter present? Is the survey highlighting fresh, accumulated or total litter? For high fresh litter totals, the top wet strand line 5 (method 7) or random (method 6) gave the highest figures. For accumulated litter, the vegetation line survey (method 8) gave the largest count. If a medium figure is desired, either survey 5 strand lines along with the vegetation (method 2) or 10 one metre belt transects from vegetation line to shoreline (method 5). Clearly it is necessary for researchers to set their parameters, then choose accordingly. However, it is critical that any bias that might arise from the survey method be borne in mind and acknowledged.

It must be stressed that all methods tested involved counting on-site versus collection and later identification, counting and weighing of litter. Many of the beaches had heavy seaweed accumulation; collecting litter would be laborious under these conditions. It was also considered inappropriate to collect litter as the methods were being tested as a quick way to assess litter present. To test formally for interactions it would be necessary to carry out repeated tests of the methods and pick up and count for an ultimate total.

Although the amount of time taken to carry out each method was not specifically recorded, from experience, any method involving the top transect line and the vegetation line were the most time consuming. The

TABLE 5

Advantages and disadvantages of the ten methods.

Method	Advantages	Disadvantages
1 (5 Strand line)	(a) covers large area of beach where items may accumulate in algae or as mats of debris left as the tide recedes	(a) can give a falsely high litter total for the beach, as areas between the strand lines can be relatively clean. (b) if only looking at surface litter, as much again may be buried in the seaweed or other debris (c) it can be difficult to identify strand lines on some beaches, they also vary daily as well as seasonally (d) not suitable for beaches with large boulders (e) may underestimate the total litter as are only counting most recent tidal-borne debris
2 (5 Strand line + vegetation line)	(b) area covered includes a good cross section of the beach, enabling the surveyor to sample both accumulated and fresh litter	(f) a–d above
3 (Top, Bottom + vegetation line)	(c) simple and takes less time than methods 1 or 2	(g) a–d above
4 (5 m wide strip)	(d) covers large area of beach where items may accumulate in algae or as mats of debris left as the tide recedes (e) if the beach has an uneven accumulation of litter, there is a better chance of surveying both 'clean' and 'dirty' areas	(h) time consuming when setting up strips if using marking strings
5 (1 m wide s trip)	(f) d & e above	(i) h above
6 (random 2×2 quadrats)	(g) fast way of sampling (h) sampling not influenced by location of litter, hence statistically valid	(j) results very variable, may depend on the amount of litter present
7 (top strand line)	(i) simple and takes less time than methods 1 and 2	(k) records only fresh litter
8 (vegetation line)	(j) simple, but records a lot of litter	(l) records only accumulated litter
9 (middle 5 m line, or could be any randomly chosen 5 m line)	(k) covers both accumulated and fresh litter (l) quick to set out	(m) the validity of this method depends heavily on the topography of the beach, as areas of litter can be easily missed
10 (middle 1 m line, or could be any randomly chosen 1 m line)	(m) as above	(n) as above

random quadrats (method 6) and the 10 one metre vegetation line to shoreline (method 5) were both reasonably quick survey methods.

Regardless of the method chosen it is necessary to consider the advantages and disadvantages of each method (Table 5). In all cases the following must be considered:

- Site topography, shape, slope and location in relation to winds and currents. Litter may build up in some areas depending on the location and aspect of the beach. Care must be taken when selecting a survey site on beaches with an uneven distribution of litter.
- Amount of seaweed or other natural debris present, all of which mask litter and make counting difficult. Removal is the obvious solution, but may prove too costly.
- Amount of litter present and composition. If large amounts of litter are present, it is easy to miss small fragments and specific items, e.g. polystyrene beads. Hence the reliability of visual counting can vary and the only solution is to collect, hand sort and identify all items. Since one of the aims of the study was to find a relatively quick but efficient way of assessing beach litter through sampling, collection was not considered to be a useful method.
- Setting boundaries can be a problem in beaches that have no clear cut end to the sands or disappear into mudflats. Logic suggests how far to go when following an ebb tide, but it can be difficult to define and dangerous to carry out in many cases.

In conclusion, choice of method for assessing the amount of litter on a beach may depend on many factors. This study assessed a variety of methods and it was found that in general strand line counts which included the vegetation line gave higher litter counts. However, these methods measure both fresh and accumulated litter. For fresh litter alone, larger figures are obtained by counting the top wet strand line litter only. For accumulated litter, the vegetation line alone produces higher counts.

The authors would like to thank Mr. Eric Caulton, Mr. Robin Henderson and Mrs. Jill Sales for their advice and assistance with this project.

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